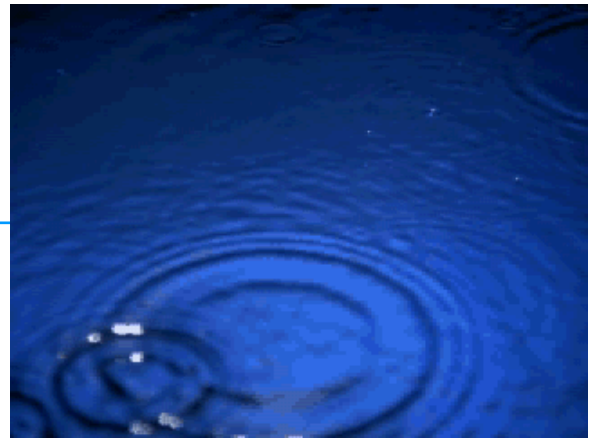
Global Precipitation Measurement

System Requirements Review
Operations and Ground System Development



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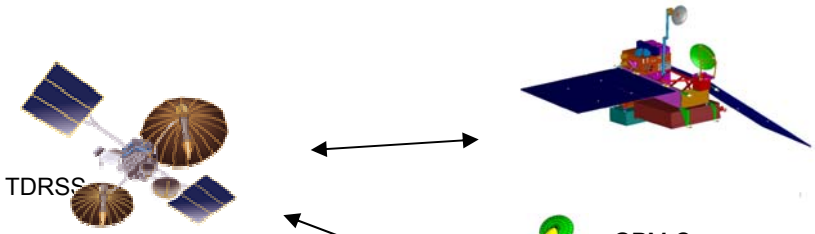
Operations and Ground System Development

- ***AGENDA:***
  - *Functional Architecture*
    - *Description of each element*
  - *Ground System/Mission Operations Driving Requirements*
    - *Mission Operations*
    - *Instrument Operations*
    - *Space/Ground Communications*
  - *Other Key Requirements/Assumptions*
  - *Operations Concept*
  - *Results of Trade Studies*
  - *Technologies Required*
  - *Requirements Verification Strategies*
  - *Additional Trade Studies to Conduct*
  - *Risk Assessment*
  - *Schedule*
  - *Issues and Concerns*

Ground System Functional Architecture



GPM Core

GPM Constellation

Precipitation Processing System (PPS) (@GSFC)
Science scheduling
Archiving
Guest Observer Support
Standard product processing

White Sands Complex:
CMD&TLM
Short Term data storage

Mission Ops Center (MOC) (@ GSFC)
RT health/safety processing
Space-Ground Protocol Processing
Commanding
Trending
Mission scheduling
Instrument data handling

L0 Science data
- NRT data
- 3 hour products
- 24 hour products

Instrument HK data
Status
Command Loads
Ops Coordination data

Instrument Science Teams
Instrument commanding
Instrument performance
Ops coordination

Products to users

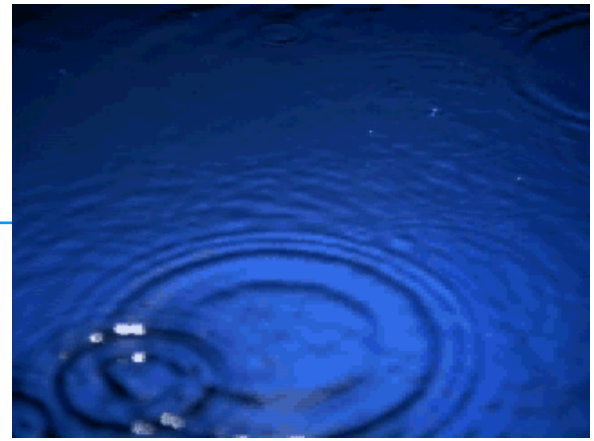
Functional Architecture Element Description (1 of 2)

- ***Tracking Data Relay Satellite System (TDRSS)***
  - *Provides forward link, and near-continuous return link capability for GPM Core and Constellation spacecraft*
- ***TDRSS Ground Terminal (TGT/White Sands, NM)***
  - *Receives return link from and uplinks forward link data to TDRSS constellation*
  - *Demodulates, bit synchronizes telemetry*
  - *Electronically interfaces with MOC to:*
    - *Receive commands*
    - *Deliver telemetry (using IP routing information)*
  - *Provides short-term telemetry storage to protect against data loss during communications link outages*
- ***Mission Operations Center (MOC/GSFC)***
  - *Provides all facilities necessary to support spacecraft operations*
    - *Real-time housekeeping data processing*
    - *Health and safety assessment*
    - *Generation, uplink, and verification of commands*
    - *SN, spacecraft, and instrument planning and scheduling*
    - *Flight Dynamics support*

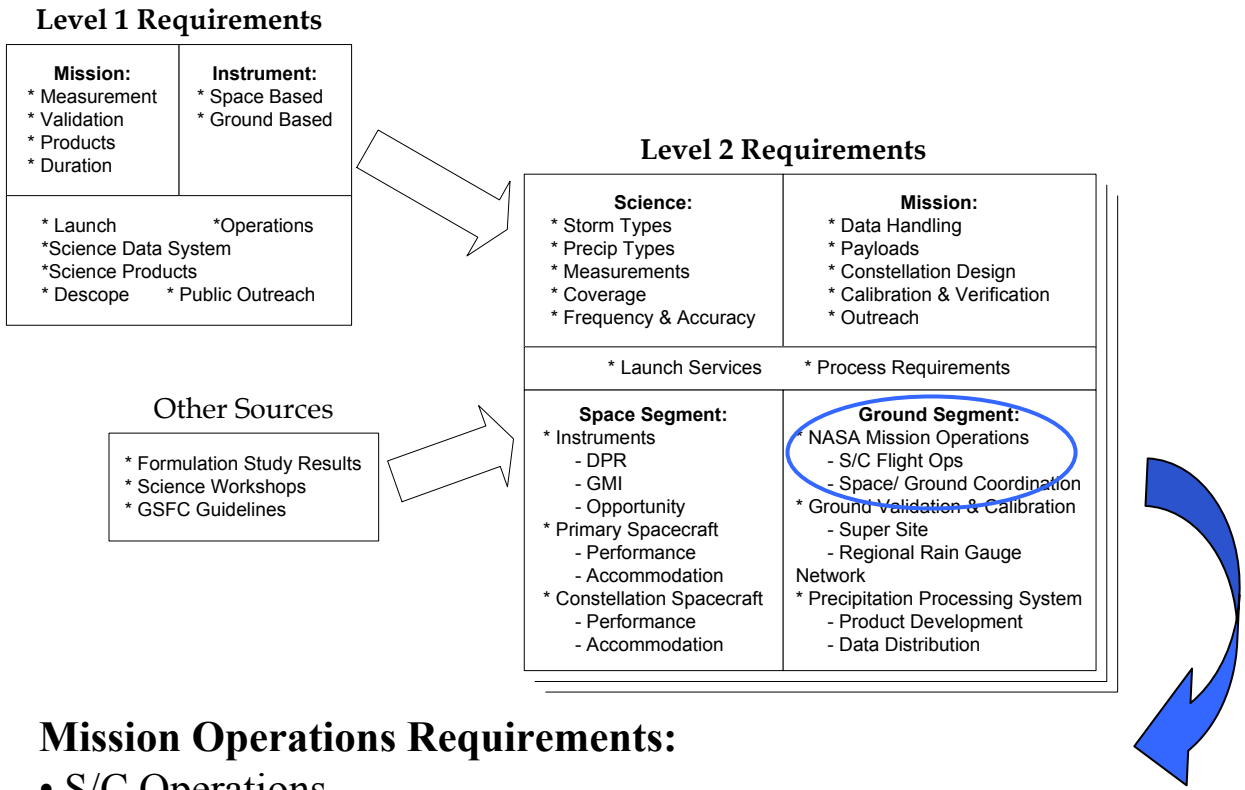
Functional Architecture Element Description (2 of 2)

- ***Mission Operations Center (MOC/GSFC) (cont.)***
  - *Receives telemetry from TGT*
    - *Performs protocol processing to "close" space-ground protocol*
  - *Interfaces with PPS to deliver 1-minute science instrument files, housekeeping data.*
  - *Interfaces with Instrument Science Teams to receive commands, command requests*
- ***Instrument Science Teams***
  - *Perform detailed health assessment of instruments*
  - *Generate instrument command loads as required*
- ***Precipitation Processing System (PPS)***
  - *Creates higher-level science data products*
  - *Delivers science data products to user community*

Ground System/Mission Operations Driving Requirements



Mission Operations Requirements - Level 2 Introduction



Mission Operations Requirements:

- S/C Operations
  - Health & Safety, CMD & TLM
  - Data Handling Flight Software
- Instrument Operations
  - Commanding Performance Monitoring
- Space/ Ground Link
  - CMD & TLM Data Rates Data Loss Allocations
  - Contingency Operations

Mission Operations Requirements - 1

- ***Mission Operations [6.3.1]***
  - ***Provide Standard MOC functionality [6.3.1.1, 6.3.1.9]:***
    - *Monitor health and safety of GPM spacecraft and instruments*
    - *Maintain flight software* ***[6.3.1.10]***
    - *Monitor telemetry and send commands*
    - *Provide activity scheduling*
    - *Provide Flight Dynamics Support*
    - *Support spacecraft and subsystem performance evaluation and assessment*
    - *Store HK telemetry for mission lifetime*
    - *Store science data short-term to support retransmissions to PPS*
  - ***Interfaces:***
    - *Receive telemetry from/send commands to space/ground link* ***[6.3.1.4]***
    - *Receive command loads/coordinate special operations with instrument ops teams* ***[6.3.1.8]***
    - *Deliver science data to PPS* ***[6.3.1.5]***

Mission Operations Requirements -2

- ***Mission Operations [6.3.1]***
  - ***Availability [6.3.1.2]***
    - *Normal Operations: 98%*
      - *Can be satisfied with single-string ADPE equipment*
    - *Critical Operations: 99.95%*
      - *Requires Fault-tolerant system implementation (simultaneously operating parallel strings or "hot-backup")*
  - ***Data Loss [6.3.1.7]***
    - *Allowable loss of less than 1% of GPM instrument data*
      - *Based upon experience with previous missions*

Mission Operations Requirements -3

- ***Mission Operations [6.3.1]***
  - *Data Delivery*
    - *Implement the ground component of the retransmission protocol* ***[6.3.1.6]***
    - *Deliver 1-minute science instrument files to the PPS in:*
      - *Near real-time for all files received in initial transmission* ***[6.3.1.5.i]***
        - *Satisfies Level 1 requirement for "best effort" NRT delivery*
      - *Every 3 hours, incorporating retransmissions* ***[6.3.1.5.ii]***
        - *Satisfies Level 1 requirement for 90% quick-look data recovery*
      - *Every 24 hours, incorporating all retransmissions* ***[6.3.1.5.iii]***
        - *Satisfies Level 1 requirement for 98% science data recovery*
    - *Maintain quality and accounting statistics describing instrument files received, instrument files delivered to PPS, and instrument data retransmitted.* ***[6.3.1.12]***

Instrument Operations Requirements

- ***Instrument Operations:*** ***[6.3.2]***
  - *Generate command loads and software loads* ***[6.3.2.1]***
    - *Provide to MOC for uplink as required*
  - *Evaluate instrument performance* ***[6.3.2.2]***
  - *Coordinate special operations with MOC* ***[6.3.2.3]***
  - *Maintain flight software for each instrument* ***[6.3.2.4]***

Space/Ground Link Requirements - 1

- ***Space/ Ground Link:*** ***[6.3.3]***
  - ***Space Network (SN)***
    - *Provide continuous return link coverage using Demand Access Service (DAS)* ***[6.3.3.1]***
      - *Derived from L1 rqs 3.1.3 and 3.4.1*
    - *DAS Data Rates* ***[6.3.3.2]***
      - *300 kbps return for Core Spacecraft, 30 kbps for Constellation spacecraft*
      - *2 kbps for commands*
    - *Provide scheduled (single-access) forward and return link services* ***[6.3.3.3]***
      - *Provides support for large command loads, recovery from large data losses*
    - *SSA Data Rates* ***[6.3.3.2]***
      - *1.4 Mbps return for Core Spacecraft, 180 kbps for Constellation spacecraft*
      - *16 kbps for commands*
    - *Provide return link data to GPM MOC in near-real-time* ***[6.3.3.4]***
    - *Record all return link data and retain for minimum of 72 hours* ***[6.3.3.5]***
    - *Allowable data loss of less than 0.5%* ***[6.3.3.6]***

Space/Ground Link Requirements - 2

- ***Space/ Ground Link:*** ***[6.3.4]***
  - ***Ground Network (GN)***
    - *Receive recorded telemetry from core, constellation spacecraft* ***[6.3.4.2]***
    - *Data Rates:* ***[6.3.4.1]***
      - *4 Mbps return for Core Spacecraft, 1.5 Mbps for Constellation spacecraft*
      - *Above data rates supported by selected NASA stations, USN*
      - *Maximum possible S-band rate required to ensure maximum data recovery under contingency operations*
    - *Uplink commands to core, constellation spacecraft @ 2 kbps* ***[6.3.4.4]***
    - *Provide real-time data to GPM MOC without delay* ***[6.3.4.3]***
      - *Real-time data limited to S/C, instrument HK. Instrument telemetry would be store and forward.*

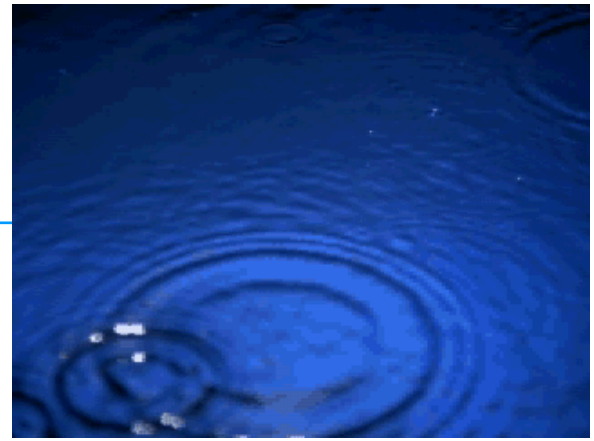
Other Key Requirements and Assumptions (1 of 2)

- ***Core Spacecraft Data Rates:***
  - *Data rate for Core Spacecraft is ~250 kbps, based on the following requirements/assumptions:*
    - *95 kbps for Precipitation Radars,(2)* ***[5.3.14.6]***
    - *15 kbps for GPM Microwave Imager* ***[5.3.14.7]***
    - *25 kbps for instrument of opportunity* ***[5.3.14.8]***
    - *12 kbps for spacecraft housekeeping data*
    - *Additional 4% on all data estimated overhead for IP protocol.*
- ***TDRSS DAS available for approximately 96% of the orbit:***
  - *There will be some small outages due primarily to TDRSS handovers, and interference with DSN operations.*
  - *Data will be stored on-board spacecraft and retransmitted using space-ground protocol.*
- ***Bit Error Rate: Provide 10^{-8} BER 99% of the time [5.3.15.5]***
- ***Given above assumptions, DAS provides sufficient bandwidth to support real-time transmission for Core spacecraft, and recover 35 minutes of data in 12 hours.***

Other Key Requirements and Assumptions (2 of 2)

- ***Instrument Operations:***
  - *Instruments operate in survey mode, with minimal command support required from the ground:*
    - *No target of opportunity operations*
    - *Occasional software changes, table loads, and calibrations are expected.*
- ***Spacecraft Operations:***
  - *Spacecraft performs autonomous orbit stationkeeping maintenance* ***[5.3.13].***
  - *Yaw maneuvers are planned and executed by mission operations staff*
    - *Frequency expected to be 30-45 days*
  - *Spacecraft Flight software monitors all major subsystems and autonomously performs safing.*
- ***MOC equipment/facilities***
  - *Core and Constellation spacecraft are operated from the same MOC system.*
    - *Decision will be revisited upon selection of Constellation spacecraft supplier.*

Mission Operations Concept



Mission Operations Concept -- Highlights

- ***Mission Operations is straightforward and can be accomplished using an 8x5 staffing profile (day shift, weekday only)***
  - *Limited commanding required*
    - *Instruments operate in survey mode and require little commanding from ground*
    - *1-2 command loads per week expected to be sufficient to control instrument/spacecraft activities.*
  - *Data Management Operations simplified through use of IP protocol*
    - *Significantly simplifies Solid State Recorder management*
      - *Retransmissions are automatically performed through uplink of appropriate protocol directives*
      - *Solid-state recorder management does not require labor-intensive effort from FOT personnel.*
  - *Similar operations staffing approach used successfully on several current similar missions (such as IMAGE, MAP, SMEX)*
  - *Technology exists allow unstaffed operations on off-shifts*
    - *Paging support available, successfully used on previous missions.*

Operations Concept -- Routine Operations (1 of 9)

- ***Routine operations activities described for the following MOC operations:***
  - *Real-time telemetry processing*
  - *Planning and Scheduling*
  - *Commanding*
  - *Flight Dynamics*
  - *Science Data Receipt, Processing and Delivery*
  - *Data Recovery*
    - *Telemetry*
    - *Commands*
  - *Other*

Operations Concept -- Routine Operations (2 of 9)

- ***Real-Time Telemetry Processing***
  - *Spacecraft:*
    - *On-board telemetry processing/monitoring is performed for all key spacecraft subsystem and instrument parameters*
    - *Safe-hold is autonomously executed if significant problem detected*
  - *Ground System/MOC:*
    - *Prime shift operations:*
      - *Spacecraft housekeeping data is received near-continuously, and is processed to determine health and safety of spacecraft*
      - *MOC automatically monitors telemetry for out-of-limit conditions*
        - *Appropriate mechanisms are used to notify FOT personnel, such as audible tones*
        - *Spacecraft engineer(s) review data to determine appropriate response to anomalies*
    - *Off-shift operations:*
      - *Spacecraft housekeeping data is received near-continuously, and is processed to determine health and safety of spacecraft*
      - *On-call FOT personnel are automatically paged upon occurrence of pre-defined out-of-limit condition.*

Operations Concept -- Routine Operations (3 of 9)

- ***Planning and Scheduling***
  - *Instrument operations:*
    - *Planned by instrument teams in coordination with project scientist*
    - *Types of operations (may not apply to GMI instrument):*
      - *Instrument calibrations (expected ~weekly for Precipitation Radar)*
      - *Software changes*
      - *Table loads*
  - *Spacecraft operations:*
    - *Planned by spacecraft engineer(s) within MOC*
  - *Integrated timeline created by MOC planners to integrate spacecraft and instrument plans*
    - *Conflicts, if any, are identified, and resolved with instrument teams (conflicts are expected to rarely occur).*
  - *Ground system:*
    - *Schedule requests for forward link, return link services are coordinated by MOC planners through Network Control Center.*
      - *Forward link services scheduled include normal command load activity plus retransmission requests.*

Operations Concept -- Routine Operations (4 of 9)

- ***Commanding:***
  - *Spacecraft/instrument operations:*
    - *MOC personnel create/format command loads and uplink them during a scheduled TDRSS forward link session*
    - *Simple instrument commands are directly generated by MOC personnel after coordination with instrument team*
    - *More complicated instrument commands (such as software uploads) are created directly by instrument teams and sent to MOC, where they are integrated with spacecraft command loads.*
    - *Command load frequency expected to be 1-2 loads per week.*
    - *Spacecraft/instrument commands require "person-in-the-loop" to initiate uplink*
  - *Retransmissions of data:*
    - *Commands requesting retransmission of partially received/unsuccessfully received files are automatically generated by space-ground protocol, and uplinked approximately every 3 hours per TDRSS schedule*
    - *Retransmission requests are delivered autonomously to spacecraft, without "person-in-the-loop"*

Operations Concept -- Routine Operations (5 of 9)

- ***Flight Dynamics:***
  - *Most of routine Flight Dynamics operations are performed autonomously by spacecraft:*
    - *GPS sensors used to provide on-board orbit data.*
    - *Attitude sensors control spacecraft attitude*
    - *Autonomous orbit maintenance (stationkeeping) planned for GPM*
      - *Can be overridden/turned-off via ground control as necessary*
  - *FOT personnel perform following activities:*
    - *Calculating predicted orbit for use in determining advance TDRSS schedules, and use by PPS.*
    - *Planning other major maneuvers*
      - *Orbit raising maneuvers as required*
      - *Yaw maneuvers for core spacecraft (to preserve proper solar array pointing)*
      - *Maneuvers to support instrument calibration as required*

Operations Concept -- Routine Operations (6 of 9)

- ***Data Receipt***
  - *FOT personnel monitor quality of TDRSS downlink using TDRSS status information as well as quality/accounting data internal to the MOC*
    - *FOT personnel are paged to respond to significant downlink problems if anomalies occur on off-shifts*
  - *FOT personnel coordinate with TDRSS operators as necessary to resolve large outages.*
- ***Data Processing and Delivery***
  - *Return link processing and delivery to PPS occurs automatically, requiring no FOT intervention*
  - *FOT personnel coordinate with PPS, NISN personnel to resolve communications problems when necessary*
  - *FOT personnel initiate manual procedures to re-deliver science data to the PPS, to recover from PPS operational problems.*

Operations Concept -- Routine Operations (7 of 9)

- ***Return Link Telemetry: Data Recovery -- Identification of Missing/Damaged Data***
  - *Software task within MOC will automatically identify portions of files (typically blocks, or packets within blocks) unsuccessfully transmitted from space to ground, using IP protocol information/algorithms*
    - *Protocol will automatically generate retransmission requests and queue them for uplink to the spacecraft.*
  - *Spacecraft will queue files during TDRSS handover periods, and deliver when communications are re-established using available bandwidth.*

Operations Concept -- Routine Operations (8 of 9)

- ***Return Link Telemetry: Data Recovery -- Requesting/Receiving Retransmissions***
  - *MOC will periodically automatically uplink retransmission requests, and will receive retransmitted data on same link as real-time transmissions.*
    - *TDRSS Multiple Access (MA) forward and return services will nominally be used*
    - *Retransmission requests will be delivered in accordance with the established TDRSS schedule, as follows:*
      - *Every 3 hours, to support creation of the 3-hour PPS product*
      - *Every 24 hours, to support creation of the 24-hour PPS product*
  - *In cases of severe loss/outage (e.g., an entire TDRSS contact), Operations personnel will manually schedule a TDRSS SSA contact to request retransmissions/redeliver data.*
    - *Normal MA support will be suspended for the duration of the SSA contact.*
- ***Forward Link Commands: Data Recovery***
  - *No special operations performed -- MOC uses guaranteed delivery protocol (TCP/IP) to send commands to the spacecraft in majority of instances*
    - *Acknowledgement/retransmission of commands occur automatically via protocol*

Operations Concept -- Routine Operations (9 of 9)

- ***Other operations:***
  - *Long Term Performance Assessment*
    - *Spacecraft housekeeping data stored at MOC for the life of the mission*
    - *Spacecraft engineer investigates long-term performance trends for all major subsystems, develops operational workarounds or procedures as necessary to avoid future spacecraft anomalies where possible*
  - *Clock Correction*
    - *Time is normally controlled on-board spacecraft through use of GPS receiver*
    - *Backup procedures will be in place in MOC to perform clock correction if needed (using Network Time Protocol).*

Mission Operations -- Trade Study Results

- ***SN vs. GN trade study***
  - *Purpose: Determine best approach to providing Space-Ground Communications for GPM primary/constellation spacecraft*
  - *Results: SN exhibits clear advantage for GPM space-ground communications*
  - *Factors:*
    - *SN provides best solution for satisfying Level 1 requirement for Immediate Products*
      - *Contact available over 100% of orbit, effective coverage is 96% of orbit with TDRSS handovers*
      - *GN coverage only provides 9% of orbit given orbit altitude, inclination of S/C*
    - *Cost:*
      - *Space-Ground communications cost for Primary/Constellation spacecraft can be satisfied for ~1.5M year.*
      - *GN solution would be a minimum of 5.5M/year (assuming one contact per orbit per spacecraft using commercial provider).*
    - *Scheduling Complexity: GN solution much less desirable due to:*
      - *Potential conflicts for station resources with other spacecraft*
      - *Operational complexity for scheduling additional contacts/resources*

Mission Operations -- Requirements Verification Strategies

- ***Full Testing Lifecycle will be used to Verify MOC/Ground System performance prior to launch***
- ***Appropriate Test Plans/Procedures will be documented for each phase of testing***
- ***Ground System Testing goal is to verify performance, functionality of each Ground System Element, and includes***
  - *Developer Level testing for each component*
  - *Formal Acceptance Testing of each Subsystem*
  - *Network Compatibility Tests*
- ***Spacecraft-Ground System Interface Test goal is to ensure compatibility of spacecraft-ground system interfaces, and includes***
  - *Tests with Spacecraft Simulator*
  - *Spacecraft Interface Tests (hardline to S/C)*
  - *Thermal Vac Tests*
- ***Operations Readiness Testing goal is to ensure readiness of FOT personnel and procedures prior to launch, and includes***
  - *Operations Readiness Exercises, Formal Mission Operations Readiness Tests*

Mission Operations -- Technologies Required

- ***No new technology development is required for GPM***
  - *Use of Internet protocol for space-ground communications is an adaptation of currently existing operational or prototype technologies and not development of new technology.*
- ***Technology needed to satisfy L2 requirements describing core MOC functionality is currently available.***
- ***Automation/remote access technologies required, and in use in existing control centers, include the following:***
  - *Paging support (to notify on-call personnel of anomalies, critical events)*
  - *Remote access to certain control center functions (I.e., trending system) through WWW*
  - *Automation of "routine" mission operations activities, such as*
    - *Delivery of data to PPS*
    - *Creation of long-term trending products*
    - *Creation of flight dynamics products*

Mission Operations --Additional Trades/Activities (1 of 2)

- ***Continue Ground System/Mission Operations Architecture Definition***
  - *Develop L3/L4 requirements for Ground Segment*
  - *Develop Ground System/MOC Operations Concept*
  - *Develop Ground System Reference Architecture*
    - *Perform Architecture Trade Studies for MOC/Ground System as needed*
  - *Develop Ground System Product Development Plan*
  - *Develop Preliminary versions of Interface Control Documents (ICDs)*
- ***Determine approach for providing operations services for Constellation Spacecraft***
  - *Options include:*
    - *Co-location with Core Spacecraft MOC facilities*
    - *Separate facility (such as a Commercial Provider)*
- ***Work with GPM partners to explore potential use of TDRSS Demand Access on partner-provided constellation spacecraft***
  - *Develop a GPM Demand Access User Guide for Partners*

Mission Operations --Additional Trades/Activities (2 of 2)

- ***Operations Concept Development:***
  - *Need to define operations "coordination" requirements with partner spacecraft operations*
    - *Constellation satellites launched by international partners*
    - *Existing satellites*
  - *Current assumption is that partner spacecraft operations contain sufficient facilities for mission operations, and do not depend upon/require any NASA facilities for mission operations.*
  - *Current requirements/operations concept do not assume any "operationally" intensive coordination requirements, such as:*
    - *Tight formation control*
    - *Tightly coordinated constellation planning/scheduling activities*
    - *Constellation performance assessment*

Mission Operations --Risk

- ***Space-Ground Communications: Use of IP protocol***
  - *No previous operational experience with use of IP as space-ground protocol, however, risk is mitigated by significant engineering/test that has been performed by many organizations to prove concepts, develop workable approaches*
    - *Current concept/architecture for space-ground communications requires no new technology development within MOC.*
- ***Mission Operations Architecture: No risks identified***
- ***Mission Operations Staffing Approach: No risks identified.***

Ground Systems / Mission Operations
Summary Schedule

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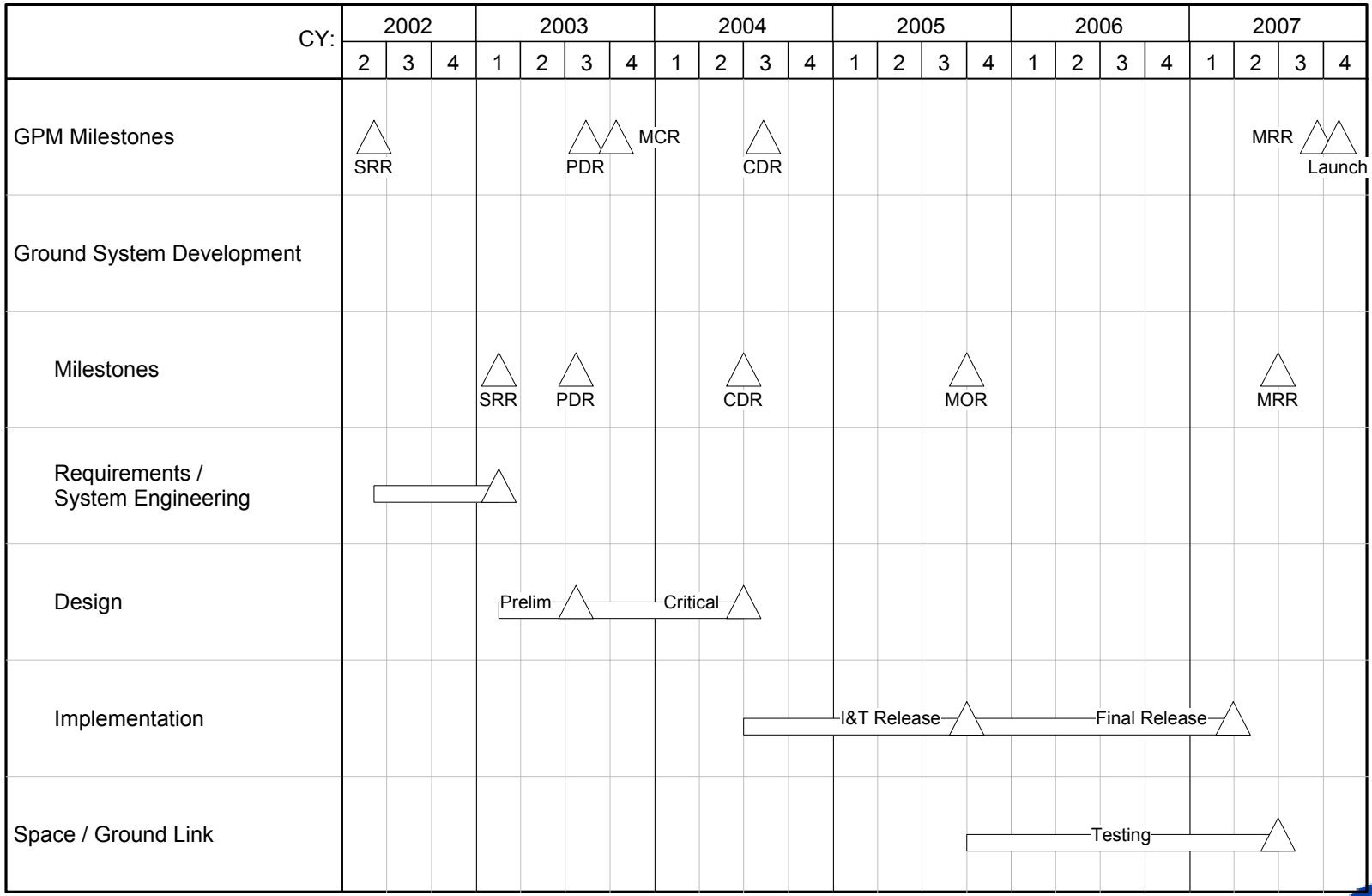

Mission Operations -- Issues and Concerns

- ***None***